



# **Optics Technology for NASA's Physics of the Cosmos (PCOS) and Cosmic Origins (COR) Programs**

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# Outline

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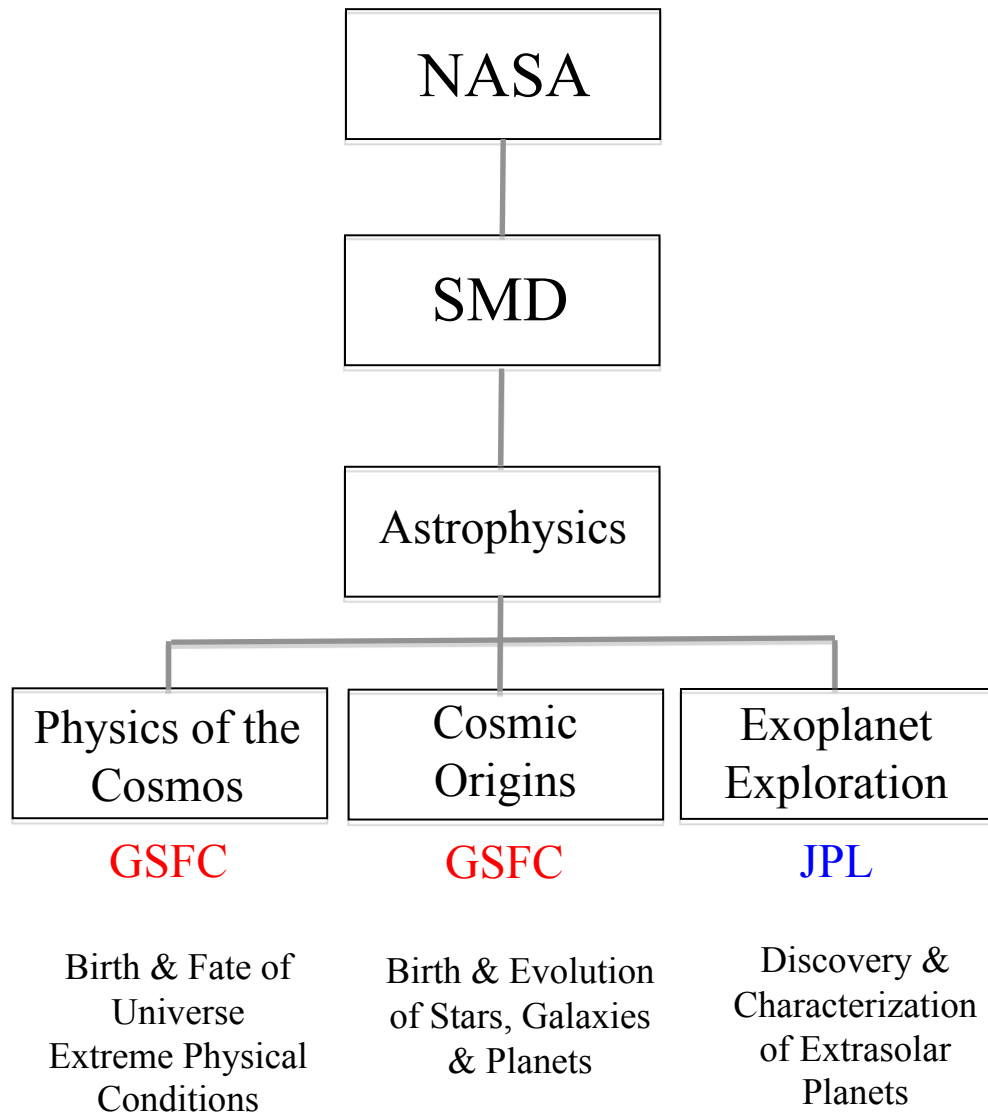
- What is PCOS and COR?
- Program Technology Management
- Optics Technology Needs for COR
- Optics Technology Needs for PCOS
- Summary

# Introduction

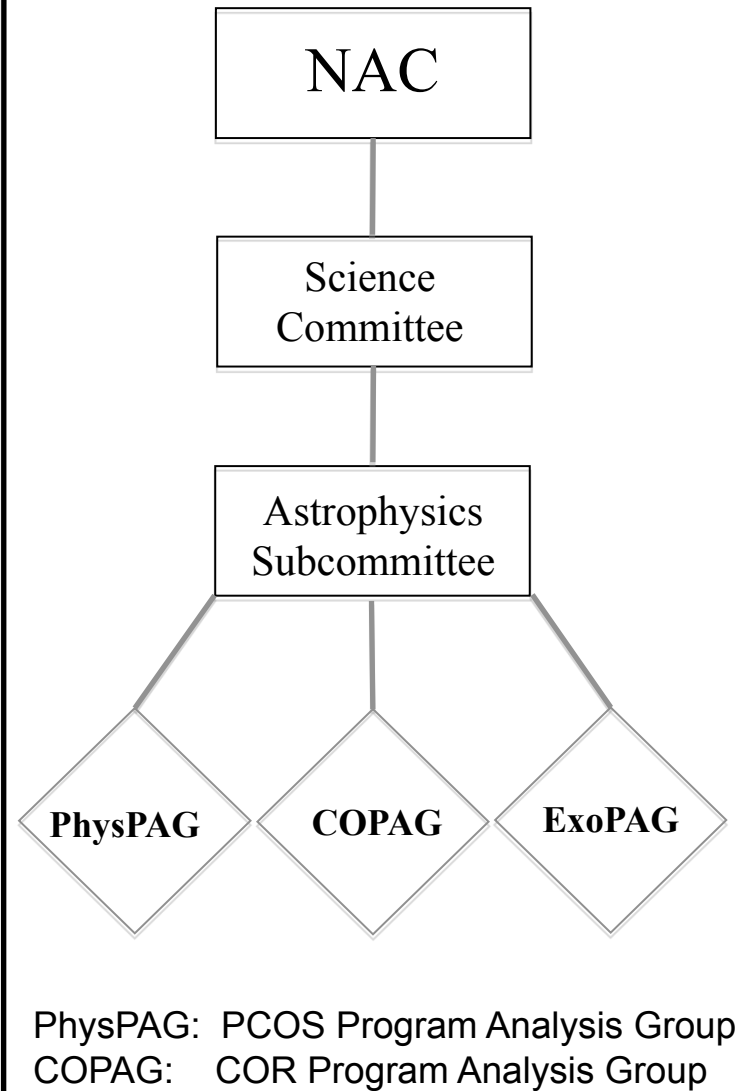
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- The Program Office is
  - A support arm for Headquarters
  - Shares partnership with HQ and Project teams for mission success
- Projects within PCOS & COR programs are
  - “Uncoupled” programmatically
  - but “Coupled” scientifically and in technology development
- Neither Program has projects in Formulation or Implementation at this time. Projects are either in
  - Study/Pre-formulation or
  - Operations

## Organizations



## Advisory Committees



## What are PCOS & COR?

Uncoupled programs comprised of a Program Office & multiple projects

PCOS	COR
<b>Science</b>	
High-energy Astrophysics	UV/Visible Astrophysics
Cosmology	Infrared Astrophysics
Fundamental Physics	
<b>Operating Missions (Phase E)</b>	
Chandra	Hubble (NASA/ESA)
Fermi	Spitzer
Planck (ESA)	Herschel (ESA/NASA)
XMM - Newton (ESA)	SOFIA (NASA/DLR)
INTEGRAL (ESA)	
<b>Missions in Implementation (Phases C/D)</b>	
None	None (JWST)
<b>Missions in Formulation (Phases A/B)</b>	
Euclid (ESA/NASA?)	SPICA (JAXA/NASA)
LISA (NASA/ESA)	
IXO (NASA/ESA/JAXA)	
<b>Missions in Pre-Formulation</b>	
Inflation Probe	UV/O Telescope
Black Hole Finder Probe	
<b>Supporting Research &amp; Technology</b>	

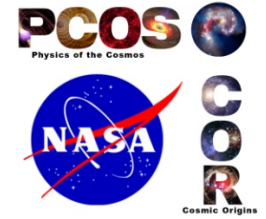
# Summary of Technology Management

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- Mission studies and technology development will be coupled as early as practical to implement an incremental push + pull development approach
- The process for allocating all technology funding will include a merit-based review and be transparent
  - Program Director serves as Source Selection Authority
  - Existing processes (e.g., NRA, AO, RFP, SBIR/STTR) will be followed
- Tasks managed by the Program Office will be vetted through the Program Technology Management Board
- The status of program technology management will be disseminated to the public with the Program Annual Technology Report

# Technology Management: Technology Bins

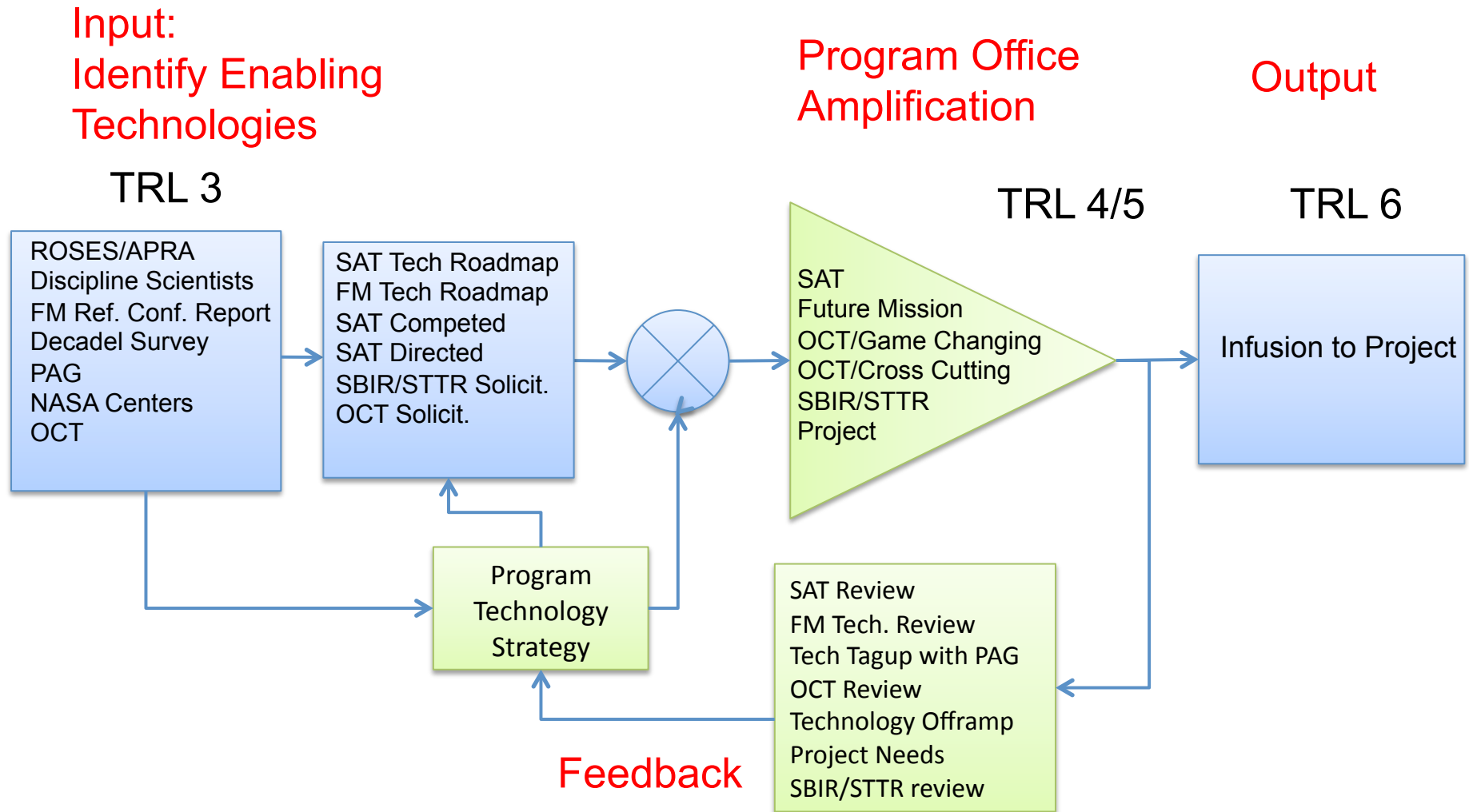
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Program Office technology development falls into three categories:

- **Program Technology** (not yet linked to mission concept)
  - Cross-cutting: technology applies to multiple science areas/mission concepts; may cross programs
  - Mid-TRL: not sufficiently mature for mission enabling or even enhancing, so maturation must be funded separately from missions (study or project)
  - Technology related to an immature mission concept: understood to enable a key science objective, but mission concept does not yet have a Technology Roadmap or Technology Development Plan (TDP) to guide development
- **Unique infrastructure** capability that serves the community
  - Examples include optical test beds and detector development and characterization labs at NASA Centers or academic institutions
- **Mission-specific technology**
  - A technology that enables a specific mission concept. The mission concept or the technology is mature enough to have a vetted Technology Development Plan to guide development, but a project office has not been established yet

# Technology Planning/Implementation Process





## COR: Optics Technology Needs

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- Recommendations from COPAG
  - *Charts 9-13, Sembach, ExoPAG/COPAG Mtg, 4/26/11*
- Large UVOIR Mission in next decade
- Reference to Astro2010 Decadal Survey
  - *Technology Investments to Meet the Needs of Astronomy at Ultraviolet Wavelengths in the 21<sup>st</sup> Century, technology white paper #54 - Sembach et al.*
  - *THEIA: Telescope for Habitable Exoplanets and Interstellar/Intergalactic Astronomy, RFI #132 - Kasdin et al.*
  - *Advanced Technology Large Aperture Space Telescope – ATLAST, RFI #13 – Postman et al.*
- *Key advances could be made with a telescope with a 4-meter diameter aperture with a large field of view and fitted with high-efficiency UV and optical cameras/spectrographs operating at shorter wavelengths than Hubble Space Telescope*

## COR: Increasing Throughput

- The throughput of optical systems at UV has considerable headroom for growth.
- Even Optical/IR designs can be improved via multiplexing.
- Technology investments can be traded against aperture size.

**Table 1: Exposure Times for Telescopes With and Without New Technology Investments**

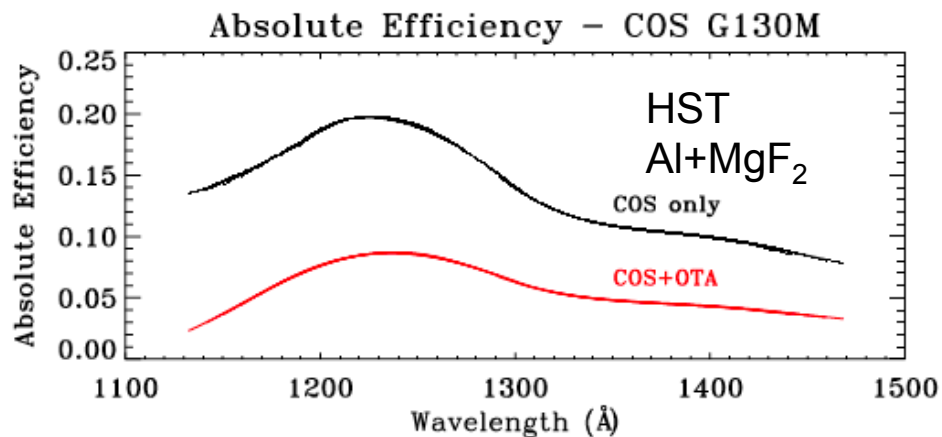
Flux ( $\text{erg cm}^{-2} \text{s}^{-1} \text{\AA}^{-1}$ )	GALEX FUV (mag)	Exposure Time to Reach S/N = 10 at R = 20,000			
		HST / COS	4m HST or Optimized 2m	8m HST or Optimized 4m	16m HST or Optimized 8m
$1 \times 10^{-15}$	19.2	9.8 ksec	3.6 ksec	900 sec	220 sec
$1 \times 10^{-16}$	21.7	115 ksec	39 ksec	9.1 ksec	2.2 ksec
$1 \times 10^{-17}$	24.2	2.9 Msec	700 ksec	110 ksec	24 ksec

Calculations assume a 2-mirror OTA with 12% secondary linear obscuration, feeding a single reflection spectrograph with a detector dark count rate of  $2.7 \times 10^{-4} \text{ cnt s}^{-1}$  per resolution element.

Optimized telescope configurations assume a factor of 4 improvement in system throughput compared to existing (Hubble) technology.

# COR: Optical Coatings

- Technology “tall poles”
  - Smoothness, surface quality/uniformity, polarization
  - High reflectivity (>90%) coatings over large bandpasses (100 nm – 1  $\mu$ m)
    - Compatibility with use at UV wavelengths is highly desirable
    - Coatings like Al + LiF may be difficult to handle on large optics

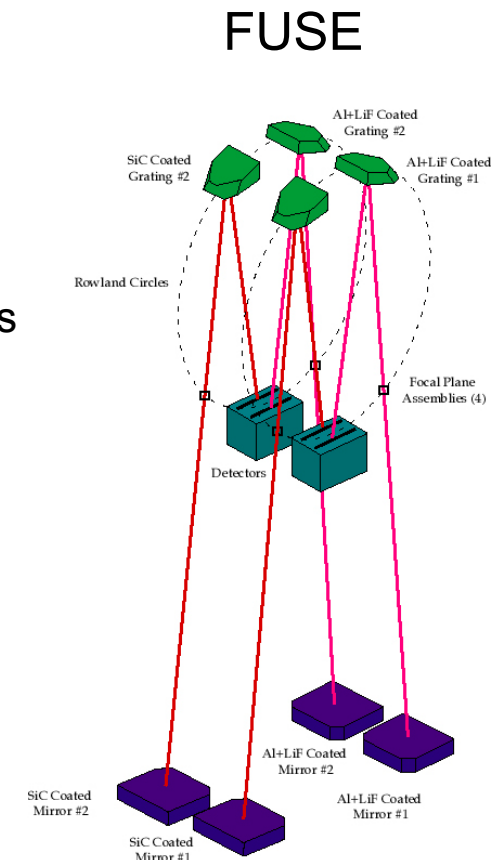
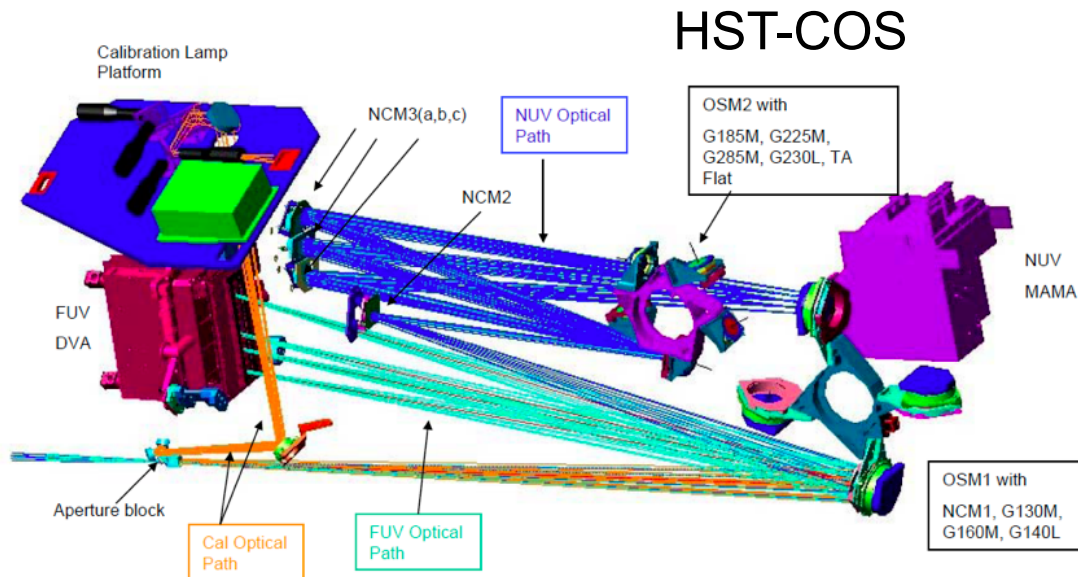


HST OTA	
115 nm	26%
120 nm	41%
150 nm	41%
200 nm	49%
250 nm	60%
300 nm	61%

Light loss for three 70% reflections = Ten 90% reflections = Twenty-one 95% reflections

# COR: Optics

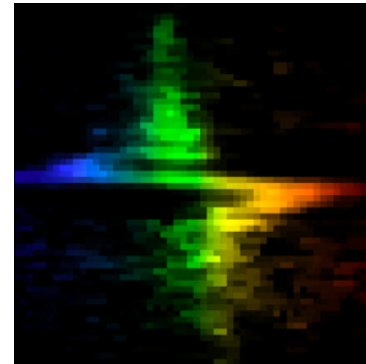
- Design complexity can improve as optics and coatings improve
- Needs
  - Large lightweight optics with areal densities  $< 20 \text{ kg/m}^2$  (and supporting pointing accuracy/stability)
  - Large aberration-correcting diffraction gratings
  - Fast optics for some applications (off-axis telescope designs - e.g. FUSE)



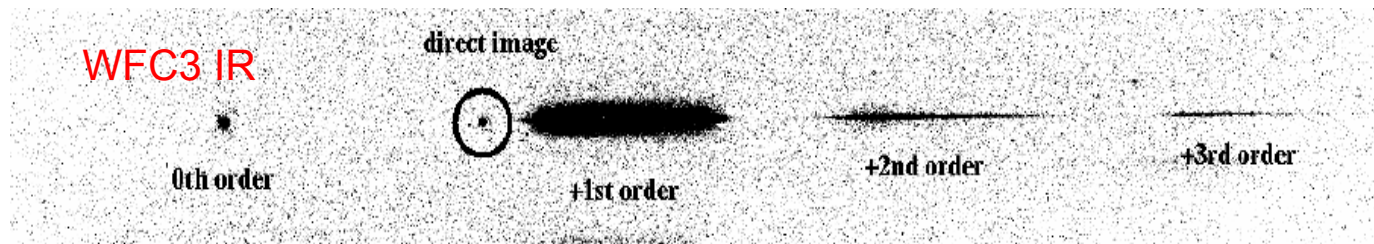
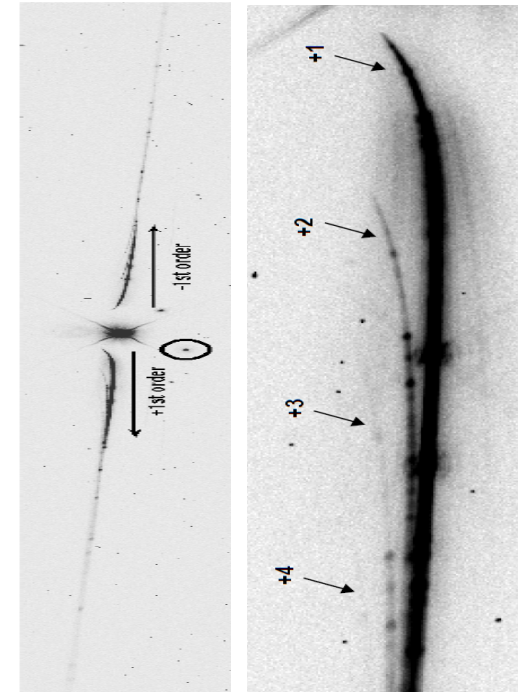
# COR: Optical Designs

- Multiplexing can improve efficiency by orders of magnitude
  - Slitless spectroscopy
  - Multi-object aperture arrays
  - Integral field units (even all reflecting IFUs in UV)
- JWST is taking advantage of spectroscopic multiplexing
  - Microshutter Array
- GRISM spectroscopy with HST-WF3 is being applied to fields ranging from Exoplanets to Cosmology

STIS



WFC3 UVIS





# PCOS: Optics Technology Needs

PhysPAG Technology Study  
Analysis Group (SAG), 5/1/11, Astro2010 Decadal

TRL4-6

TRL7-9

	WFIRST	LISA	IXO	Inflation Probe	Fundamental Physics
<b>Science Summary</b>	Study the nature of dark energy via BAO, weak lensing and S <sub>N</sub> Ia, IR survey, census of exoplanets via microlensing	Probe black hole astrophysics & gravity signatures from compact stars, binaries, and supermassive black holes	Conditions of matter accreting onto black holes, extreme physics of neutron stars, chemical enrichment of the Universe	Observe the polarization signature of inflation in the very early Universe	Precision measurements of space-time isotropy and gravitational effects
<b>Architecture</b>	Single 1.5 M dia. Telescope, with focal plane tiled with HgCdTe (TBD).	Three space craft constellation. Each spacecraft in separate, Keplerian orbit. Sub nm displacements measured by lasers (Michelson interferometer).	Single 2.5 – 3 M grazing incidence 20 M focal length X-ray telescope	Wide-field of view cooled submm 2-M class telescope with large arrays of CMB polarimeters	Individual spacecraft for space-time measurement and gravitational effects. Multiple spacecraft for precision timing of interferometric measurements.
<b>Wavelength</b>	0.4 to 1.7 $\mu$ m (TBD)	Interferometer metrology wavelength 1.064 $\mu$ m - gravity wave period 10-10,000 sec.	0.3 to 40 keV	50 - 500 GHz	
<b>Telescopes: Optics</b>	Wide FOV, ~1.5-M diameter mirror	Classical optical design Surface roughness < $\lambda/30$ , backscatter/ stray light	lightweight, replicated x-ray optics.	Wide field of view, cryogenic telescope	
<b>Telescopes: Wavefront Sensing &amp; Control and Interferometry</b>		Alignment sensing, Optical truss interferometer, Refocus mechanism			Coupling of ultra-stable lasers with high finesse optical cavities for increased stability
<b>Telescopes: Metrology &amp; Structures &amp; Lasers</b>	Classic telescope structure - HST heritage	Athermal design with a Temp gradient Dimensional stability: pm/sqrt(Hz) and $\mu$ m lifetime, angular stability < 8nrad	lightweight precision structure	Spitzer Heritage	

# PCOS: Optics Near Term Push Technologies

PhysPAG Technology Study  
Analysis Group (SAG), 5/1/11

TRL1-3

TRL4-6

TRL7-9

	Next Generation Hard X-ray Observatory	Soft X-ray and EUV	Next generation X-ray timing	Next generation Medium energy Gamma ray Observatory
<b>Science Summary</b>	Hard X-ray (5-600 keV) imaging all sky survey for Black Holes	Spectroscopy of million degree plasmas in sources and ISM to study composition	EOS of neutron stars, black hole oscillations, and other physics in extreme environments	Signatures of nucleosynthesis in SNR, transients, and other sources; AGN and black hole spectra
<b>Architecture</b>	Two wide-field(~130 x 65 deg) coded mask telescopes. Full sky ea. ~95min	Focusing optics with high resolution spectrometers based on advanced gratings	Large (>3M <sup>2</sup> ) pointed arrays of solid state devices, with collimation to isolate sources	Single platform designs to measure gamma ray lines
<b>Wavelength</b>	5-30 and 10-600 keV	5-500 Angstroms	2-80 keV	100 keV - 30 MeV
<b>Telescopes: Optics</b>	Coded aperture imaging: ~5mm thk W & ~2.5mm holes; ~0.5mm W & ~0.2mm holes	Gratings, single and multilayer coatings, nano-laminate optics	No optics; source isolation by collimator	Compton telescope on single platform
<b>Telescopes: Wavefront Sensing &amp; Control and Interferometry</b>		Actuators		
<b>Telescopes: Metrology &amp; Structures &amp; Lasers</b>	~ 5" aspect req. over ~6x~3x~1.5m telescope structures	Arcsecond attitude control to maintain resolution	Moderate accuracy pointing of very large planar array	

# PCOS: Optics Long Term Push Technologies

PhysPAG Technology Study  
Analysis Group (SAG), 5/1/11

TRL1-3

TRL4-6

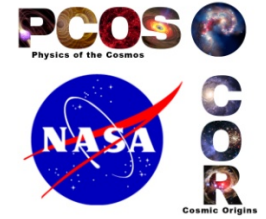
TRL7-9

	Beyond LISA (Big Bang Observer)		Beyond IXO (Gen-X)	Next generation Gamma ray focusing
<b>Science Summary</b>	To directly observe gravitational waves resulting from quantum fluctuations during the inflation of the universe		Observe the first SMBH, study growth and evolution of SMBHs, study matter at extreme conditions	Signatures of nucleosynthesis in SNR, transients, and other sources
<b>Architecture</b>	Four Michelson interferometers each of three s/c (~12 s/c total), ~50,000 km separation, LISA like	Constellation of a least 2 cold atom differential accelerometers, 10,000 km measurement baseline	16 M (50 M <sup>2</sup> ) grazing incidence telescope with 60 M focal length	2-platform designs to measure gamma ray lines
<b>Wavelength</b>	visible & near IR: gravity waves periods of ~1-10 sec	gravity wave periods 0.01 - 10 Hz	1-10 keV	100 keV - 3 MeV
<b>Telescopes: Optics</b>	~three meter precision optics	~ one meter precision optics (1/1000)	Lightweight adjustable optics to achieve 0.1 arcsec. High resolution grating spectrometer	Focusing elements (i.e. Laue lens) on long boom or separate platform
<b>Telescopes: Wavefront Sensing &amp; Control and Interferometry</b>	LISA Heritage	wavefront sensing with cold atoms; large area atom optics	0.1 arcsec adjustable optic	
<b>Telescopes: Metrology &amp; Structures &amp; Lasers</b>	LISA Heritage	10 W near IR, narrow line	Extendable optical bench to achieve 60 M focal length	Long booms or formation flying



# Technology Investment Opportunities: Example from COR

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- NASA HQ has made consistent investments in UV/Visible and near-IR/far-IR through the ROSES APRA grants program
  - ~ \$20M per year
- Serious strategic technology investments will also be made through the new SAT program starting in 2013
  - ~\$7M per year
- A successful combination of these research grants with the small business community participation through SBIRs will allow technology to mature and move to higher TRL levels (e.g., optical coatings).
  - This path has proven to be effective in many specific areas in the past
    - deformable mirrors, holographic techniques, gratings, MEMs, nanocarbon structures

## Summary

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- Look for Program Annual Technology Report (Fall 2011)
- Focused on mid-TRL
- Connect into technology needs and opportunities
  - SBIR/STTR
  - ROSES Strategic Astrophysics Technology Proposal Calls
  - Partnering with NASA Centers, universities, industry
  - Program Analysis Groups
  - PCOS and COR Program Offices/Chief Technologist
    - COR: <http://cor.gsfc.nasa.gov/>
    - PCOS: <http://pcos.gsfc.nasa.gov/>